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SYSTEM AND METHOD(S) OF MINE PLANNING, DESIGN AND PROCESSING

FIELD OF INVENTION

The present invention relates to the field of extracting resource(s) from a particular location. In particular, the present invention relates to the planning, design and processing related to a mine location in a manner based on enhancing the extraction of material considered of value, relative to the effort and / or time in extracting that material.

BACKGROUND ART

In the mining industry, once material of value, such as ore situated below the surface of the ground, has been discovered, there exists a need to extract that material from the ground.

In the past, one more traditional method has been to use a relatively large open cut mining technique, whereby a great volume of waste material is removed from the mine site in order for the miners to reach the material considered of value. For example, referring to Figure 1, the mine 101 is shown with its valuable material 102 situated at a distance below the ground surface 103. In the past, most of the (waste) material 104 had to be removed so that the valuable material 102 could be exposed and extracted from the mine 101. In the past, this waste material was removed in a series of progressive layers 105, which are ever diminishing in area, until the valuable material 102 was exposed for extraction. This is not considered to be an efficient mining process, as a great deal of waste material must be removed, stored and returned at a later time to the mine site 101, in order to extract the valuable material 102. It is desirable to reduce the volume of waste material that must be removed prior to extracting the valuable material.

The open cut method exemplified in Figure 1 is viewed as particularly inefficient where the valuable resource is located to one side of the pit 105 of a desirable mine site 101. For example, Figure 2 illustrates such a situation. The valuable material 102 is located to one side of the pit 105. In such a situation, it is not considered efficient to remove the waste material 104 from region 206, that is where the waste material is not located relatively close to the valuable material 102, but it is considered desirable to remove the waste material 104 from region 207, that is where it is located nearer to the valuable material 102. This then

brings other considerations to the fore. For example, it would be desirable to determine the boundary between regions 206 and 207, so that not too much undesirable waste material is removed (region 206), yet enough is removed to ensure safety factors are considered, such as cave-ins, etc. This then leads to a further consideration of the need to design a 'pit' 105 with a relatively optimal design having consideration for the location of the valuable material, relative to the waste material and other issues, such as safety factors.

This further consideration has led to an analysis of pit design, and a technique of removing waste material and valuable material called 'pushbacks'. This technique is illustrated in Figure 3. Basically, the pit 105 is designed to an extent that the waste material 104 to be removed is minimised, but still enabling extraction of the valuable material 102. The technique uses 'blocks' 308 which represent smaller volumes of material. The area proximate the valuable material is divided into a number of blocks 308. It is then a matter of determining which blocks need to be removed in order to enable access to the valuable material 102. This determination of 'blocks 308', then gives rise to the design or extent of the pit 105.

Figure 3 represents the mine as a two dimensional area, however, it should be appreciated that the mine is a three dimensional area. Thus the blocks 308 to be removed are determined in phases, and cones, which represent more accurately a three dimensional 'volume' which volume will ultimately form the pit 105.

Further consideration can be given to the prior art situation illustrated in Figure 3. Consideration should be given to the scheduling of the removal of blocks. In effect, what is the best order of block removal, when other business aspects such as time/value and discounted cash flows are taken into account? There is a need to find a relatively optimal order of block removal which gives a relatively maximum value for a relatively minimum effort/time.

Attempts have been made in the past to find this 'optimum' block order by determining which block(s) 308 should be removed relative to a 'violation free' order. Turning to the illustration in Figure 4, a pit 105 is shown with valuable material 102. For the purposes of discussion, if it was desirable to remove block 414, then there is considered to be a 'violation' if we determined a schedule of

block removal which started by removing block 414 or blocks 414, 412 & 413 before blocks 409, 410 and 411 were removed. In other words, a violation free schedule would seek to remove other blocks 409, 410, 411, 412 and 413 before block 414. (It is important to note that the block number does not necessarily indicate a preferential order of block removal).

It can also be seen that this block scheduling can be extended to the entire pit 105 in order to remove the waste material 104 and the valuable material 102. With this violation free order schedule in mind, prior art attempts have been made. Figure 5 illustrates one such attempt. Taking the blocks of Figure 4, the blocks are numbered and sorted according to a 'mineable block order' having regard to practical mining techniques and other mine factors, such as safety etc and is illustrated by table 515. The blocks in table 515 are then sorted 516 with regard to Net Present Value (NPV) and is based on push back design via Life-of-mine NPV sequencing, taking into account obtaining the most value block from the ground at the earliest time. To illustrate the NPV sorting, and turning again to Figure 4, there is a question as which of blocks 409, 410 or 411 should be removed first. All three blocks can be removed from the point of view of the ability to mine them, but it may, for example, be more economic to remove block 410, before block 409. Removing blocks 409, 410 or 411 does not lead to 'violations' thus consideration can be given to the order of block removal which is more economic.

The NPV sorting is conducted in a manner which does not lead to violations of the 'violation free order', and provides a table 517 listing an 'executable block order'. In other words, this prior art technique leads to a listing of blocks, in an order which determines their removal having regard to the ability to mine them, and the economic return for doing so.

Furthermore, a number of prior art techniques are considered to take a relatively simple view of the problems confronted by the mine designer in a 'real world' mine situation. For example, the size, complexity, nature of blocks, grade and other engineering constraints and time taken to undertake a mining operation is often not fully taken into account in prior art techniques, leading to computational problems or errors in the mine design. Such errors can have significant financial and safety implications for the mine operator.

With regard to size, for example, prior art techniques fail to adequately take account of the size of a 'block'. Depending on the size of the overall project, a 'block' may be quite large, taking some weeks, months or even years to mine. If this is the case, many assumptions made in prior art techniques fail to give sufficient accuracy for the modem day business environment.

Given that many of the mine designs are mathematically and computational complex, according to prior art techniques, if the size of the blocks were reduced for greater accuracy, the result will be that either the optimisation techniques used will be time in feasible (that is they will take an inordinately long time to complete), or other assumptions will have to be made concerning aspects of the mine design such as mining rates, processing rates, etc which will result in a decrease the accuracy of the mine design solution.

Some examples of commercial software do use mixed integer programming engines, however, the method of aggregating blocks requires further improvement. For example, it is considered that product 'ECSI Maximiser' by ECS International Pty Ltd uses a form of integer optimisation in their pushback design, but the optimisation is local in time, and it's problem formulation is considered too large to optimise globally over the life of a mine. Also the product 'MineMax' by MineMAX Ptd Ltd may be used to find a rudimentary optimal block sequencing with a mixed integer programming engine, however it is considered that it's method of aggregation does not respect slopes as is required in many situations. 'MineMax' also optimises locally in time, and not globally. Thus, where there is a large number of variables, the user must resort to subdividing the pit into separate sections, and perform separate optimisations on each section, and thus the optimisation is not global over the entire pit. It is considered desirable to have an optimisation that is global in both space and time.

There still exists a need, however, to improve prior art techniques. Given that mining projects, on the whole, are relatively large scale operations, even small improvements in prior art techniques can represent millions of dollars in savings, and / or greater productivity and / or safety.

An object of the present invention is to provide an improved method of determining a cluster.

Another object of the present invention is to alleviate at least one disadvantage of the prior art.

Any discussion of documents, devices, acts or knowledge in this specification is included to explain the context of the invention. It should not be taken as an admission that any of the material forms a part of the prior art base or the common general knowledge in the relevant art in Australia or elsewhere on or before the priority date of the disclosure and claims herein.

SUMMARY OF INVENTION

The present invention provides a method of and apparatus for determining a schedule for extraction of clump(s), the method including determining a period of time corresponding to at least a portion of the clump(s), and assigning the period of time to the portion of clump(s).

The present invention also provides a method of determining an extraction order of block(s) from corresponding clump(s), the method including:

performing the method of determining a schedule as disclosed herein,

determining which portion(s) of clump(s) have been assigned the same period of time, and joining together blocks located in the portion(s) having the same period of time.

Other aspects and preferred aspects are disclosed in the specification and / or defined in the appended claims.

The method(s), systems and techniques disclosed in this application may be used in conjunction with prior art integer programming engines. Many aspects of the present disclosure serve to improve the performance of the use of such engines and the use of other known mine design techniques.

In essence, the present invention, referred to as Determination of a block ordering from a clump ordering, turns a clump ordering into an ordering of blocks. This is, in effect, a de aggregation. Using techniques disclosed herein, an integer program engine may be used on the relatively small number of clumps, and thus the result can now be translated back into the large number of small blocks.

In other words, the present invention involves, in part, determining a block list or order for extraction on a periodic or period, time basis.

Other related aspects of invention, include:

In essence, the first related aspect of invention, referred to as Generic Klumpking, is a method of mine design that firstly, is considered a clever choice of aggregation to reduce the number of variables via a spatial/value clustering and propagation to form clumps. Secondly, the inclusion of mining and processing constraints in an integer program based around the clump variables to ultimately produce an optimal block sequence. Thirdly, the rapid loop of clustering blocks in this optimal sequence according to space/time of extraction and propagating these clusters to form pushbacks, interrogating them for value and mineability, and adjusting clustering parameters as needed.

In essence, the second related aspect of invention, referred to as Initial Identification of Clusters, aggregates a number of blocks into collections or clusters. The clusters preferably more sharply identify regions of high-grade and low-grade materials, while maintaining a spatial compactness of a cluster. The clusters are formed by blocks having certain x, y, z spatial coordinates, combined with another coordinate, representing a number of selected values, such as grade or value. The advantage of this is to produce inverted cones that are relatively tightly focused around regions of high grade so as not to necessitate extra stripping.

In essence, a third aspect of invention, referred to as Propagation of clusters and formation of clumps, forms relatively minimal inverted cones with clusters at their apex and intersects these cones to form clumps, or aggregations of blocks that respect slope constraints. Advantageously, it has been found that aggregating the small blocks in an intelligent way serves to reduce the number of "atoms" variables to be fed into the mixed integer programming engine. The clumps allow relatively maximum flexibility in potential mining schedules, while keeping variable numbers to a minimum. The collection of clumps has three important properties. Firstly, the clumps allow access to all the targets as quickly as possible (minimality), and secondly the clumps allow many possible orders of access to the identified ore targets (flexibility). Thirdly, because cones are used, and due to the nature of the cone(s), an extraction ordering of the clumps that is feasible according to the precedence arcs will automatically respect and accommodate minimum slope constraints. Thus, the slope constraints are automatically built into this aspect of invention.

In essence, a fourth related aspect of invention, referred to as splitting of waste and ore in clumps, is based on the realisation that clumps contain both ore blocks and waste blocks. Many integer programs assume that the value is distributed uniformly within a clump. This is, however, not true. Typically, clumps will have higher value near their base. This is because most of the value is lower underground while closer to the surface one tends to have more waste blocks. By splitting the clump into relatively pure waste and desirable material, the assumption of uniformity of value for each portion of the clump is more accurate.

In essence, a fifth related aspect of invention, referred to as Aggregation of blocks into clumps; high-level ideas, reduces the number of variables to a relatively manageable amount for use in current technology of integer programming engines. Advantageously, this aspect enables the use of an integer programming engine and the ability to incorporate further constraints such as mining, processing, and marketing capacities, and grade constraints.

In essence, a sixth related aspect of invention, referred to as 'fuzzy clustering; second identification of clusters for pushback design, clusters blocks according to their spatial position and their time of extraction. This is considered necessary because if pushbacks were formed from the block sequence in its raw form, the pushbacks would be generally highly fragmented and considered non-mineable. The clustering gives control over the connectivity and mineability of the resulting pushbacks.

In essence, a seventh related aspect of invention, referred to as fuzzy clustering; alternative 1, clusters blocks according to their spatial position and their time of extraction. The clusters may be controlled to be a certain size, or have a certain rock tonnage or ore tonnage. The shapes of the clusters may be controlled through parameters that balance the space and the time coordinate. The advantage of shape control is to produce pushbacks that are mineable and not fragmented. The advantage of size control is the ability to control stripping ratios in years where the mill may be operating under capacity.

In essence, an eighth related aspect of invention, referred to as fuzzy clustering; alternative 2, propagates inverted cones from the clusters identified in the secondary clustering. The clusters in the secondary clustering are time ordered, and the propagation occurs in this time order, with no intersections of

inverted cones allowed. Advantageously, this provides the ability to extract pushbacks from the block ordering that are well connected and mineable, while retaining the bulk of the NPV optimality of the block sequence.

In essence, a ninth related aspect of invention, referred to as fuzzy clustering; alternative 3, provides the creation of a feedback loop of clustering, propagating to find pushbacks, valuing relatively quickly, and then feeding this information back into the choice of clustering parameters. The advantage of this is that the effect of different clustering parameters may be very quickly checked for NPV and mineability. It is heretofore been virtually impossible to evaluate a pushback design for NPV and mineability before it has been constructed, and the fast process loop of this aspect allows many high-quality pushbacks designs to be constructed and evaluated (by the human eye in the case of mineability).

The present invention may be used, for example, by mine planners to design relatively optimal pushbacks for open cut mines. Advantageously, the present invention is considered is different to prior art pushback design software in that:

- The present invention does not use either of the most common pit design algorithms (Lerchs-Grossmann or Floating Cone) but instead uses a unique concept of optimal "clump" sequencing to develop an optimal block sequence that is then used as a basis for pushback design.
- The design is relatively optimal with respect to properly discounted block values. No other pushback design software is considered to correctly allow for the effect of time (viz: block value discounting) in the pushback design step. Traditional phase designs ignore medium grade ore pods close to the surface with good NPV whilst focussing on higher value pods that may be deeply buried.
- The present invention can properly address the so-called "Whittle-gap" problem where consecutive Lerchs-Grossmann shells can be very far apart, offering little temporal information. The present invention obtains relatively complete and accurate temporal information on the block ordering.
- Process and mining constraints can be explicitly incorporated into the pushback design step.

- The planner can rapidly design and value pushbacks that have different topologies, the trade-off being between pits with high NPV, but with difficult-to-mine (eg: ring) pushback shapes, and those with more mineable pushback shapes but lower NPV. The advantage of the more mineable pushback shapes is that much less NPV will be wasted in enforcing minimum mining width and in accommodating pit access (roads and berms).
- The ability to quickly generate and evaluate a number of different sets of candidate pushback designs is a feature not allowed in traditional pushback design software where design options are usually fairly limited (eg: the amalgamation of adjacent Whittle shells into a single pushback)
- Various aspects of the present invention also serve to improve the use of existing integer programming engines, such as "cplex" by ILOG.

Throughout the specification:

1. 'collection' is a term for a group of objects,
2. a 'cluster' is a collection of ore blocks or blocks of otherwise desirable material that are relatively close to one another in terms of space and / or other attributes,
3. a 'clump' is formed from a cluster by first producing a substantially minimal inverted cone extending from the cluster to the surface of the pit by propagating all blocks in the cluster upwards using the arcs that describe the minimal slope constraints. Each cluster will have its own minimal inverted cone. These minimal inverted cones are then intersect with one another and the intersections form clumps, and
4. an 'aggregation' is a term, although mostly applied to collections of blocks that are spatially connected (no "holes" in them). For example, a clump may be an aggregation, or may be "Super blocks" that are larger cubes made by joining together smaller cubes or blocks.

DESCRIPTION OF DRAWINGS

Further disclosure, objects, advantages and aspects of the present application may be better understood by those skilled in the relevant art with reference to the following description of preferred embodiments taken in conjunction with the accompanying drawings, in which:

Figures 1 to 5 illustrate prior art mining techniques.

Figure 6 illustrates, schematically, a flow chart outlining the overall process according to one aspect of invention,

Figure 7 illustrates schematically the identification of clusters,

Figure 8 illustrates schematically cone propagation in pit design,

Figure 9 illustrates schematically the splitting or ore from waste material,

Figure 10 illustrates an example of 'fuzzy clustering' in a mine site, and

Figures 11a, 11b and 11c illustrate a secondary clustering, propagation, and NPV valuation process.

DETAILED DESCRIPTION

In order to more fully describe the present invention, a number of related aspects will also be described. In this way, the reader can gain a better understanding of the context and scope of the present invention. The present invention is primarily described in sections 1 and 6 below, however, regard should also be made to the other disclosure of this specification.

1 Generic KlumpKing

Figure 6 illustrates, schematically an overall representation of one aspect of invention.

Although specific aspects of various elements of the overall flow chart are discussed below in more detail, it may be helpful to provide an outline of the flow chart illustrated in Figure 6.

Block model 601, mining and processing parameters 602 and slope constraints 603 are provided as input parameters. When combined, precedence arcs 604 are provided. For a given block, arcs will point to other blocks that must be removed before the given block can be removed.

As typically, the number of blocks can be very large, at 605, blocks are aggregated into larger collections, and clustered. Cones are propagated from respective clusters and clumps are then created 606 at intersections of cones. The number of clumps is now much smaller than the number of blocks, and clumps include slope constraints. At 607, the clumps may then be scheduled in a manner according to specified criteria, for example, mining and processing constraints and NPV. It is of great advantage that the scheduling occurs with clumps (which number much less than blocks). It is, in part, the reduced number

of clumps that provides a relative degree of arithmetic simplicity and / or reduced requirements of the programming engine or algorithms used to determine the schedule. Following this, a schedule of individual block order can be determined from the clump schedule, by de-aggregating. The step of polish at 608 is optional, but does improve the value of the block sequence.

From the block ordering, pushbacks can be designed 609. Secondary clustering can be undertaken 610, with an additional fourth co-ordinate. The fourth co-ordinate may be time, for example, but may also be any other desirable value or parameter. From here, cones are again propagated from the clusters, but in a sequence commensurate with the fourth co-ordinate. Any blocks already assigned to previously propagated cones are not included in the next cone propagation. Pushbacks are formed 611 from these propagated cones. Pushbacks may be viewed for mineability 612. An assessment as to a balance between mineability and NPV can be made at 613, whether in accordance with a predetermined parameter or not. The pushback design can be repeated if necessary via path 614.

Other consideration can also be taken into account, such as minimum mining width 615, and validation 616. Balances can be taken into account for mining constraints, downstream processing constraints and / or stockpiling options, such as blending and supply chain determination and / or evaluation.

The following description focuses on a number of aspects of invention which reside within the overall flow chart disclosed above. For the purposes of Figure 6, sections 2 and 5 are associated with 605, sections 3, 4 and 5 are associated with 606, sections 4, 6 are associated with 607, sections 7 and 7.3 are associated with 610, sections 7.2 and 7.3 are associated with 611, section 7.3 is associated with 612, 613 and 614, and sections 7, 7.1, 7.2 and 7.3 are associated with 609.

1.1 Inputs and preliminaries

Input parameters include the block model 601, mining and processing parameters 602, and slope constraints 603. Slope regions (eg. physical areas or zones) are contained in 601; slope parameters (eg. slopes and bearings for each zone) are contained in 602.

The block model 601 contains information, for example, such as the value of a block in dollars, the grade of the block in grams per tonne, the tonnage of rock in the block, and the tonnage of ore in the block.

The mining and processing parameters 602 are expressed in terms of tonnes per year that may be mined or processed subject to capacity constraints.

The slope constraints 603 contain information about the maximal slope around in given directions about a particular block.

The slope constraints 603 and the block model 601 when combined give rise to precedence arcs 604. For a given block, arcs will point from the given block to all other blocks that must be removed before the given block. The number of arcs is reduced by storing them in an inductive, where, for example, in two dimensions, an inverted cone of blocks may be described by every block pointing to the three blocks centred immediately above it. This principle can also be applied to three dimensions. If the inverted cone is large, for example having a depth of 10 , the number of arcs required would be 100; one for each block. However, using the inductive rule of "point to the three blocks centred directly above you", the entire inverted cone may be described by only three arcs instead of the 100. In this way the number of arcs required to be stored is greatly reduced. As block models typically contain hundreds of thousands of blocks, with each block containing hundreds of arcs, this data compression is considered a significant advantage.

1.2 Producing an optimal block ordering

The number of blocks in the block model 601 is typically far too large to schedule individually, therefore it is desirable to aggregate the blocks into larger collections, and then to schedule these larger collections. To proceed with this aggregation, the ore blocks are clustered 605 (these are typically located towards the bottom of the pit. In one preferred form, those blocks with negative value, which are taken to be waste, are not clustered). The ore blocks are clustered spatially (using their x, y, z coordinates) and in terms of their grade or value. A balance is struck between having spatially compact clusters, and clusters with similar grade or value within them. These clusters will form the kernels of the atoms of aggregation.

From each cluster, an (imaginary) inverted cone is formed, by propagating upwards using the precedence arcs. This inverted cone represents the minimal amount of material that must be excavated before the entire cluster can be extracted. Ideally, for every cluster, there is an inverted cone. Typically, these cones will intersect. Each of these intersections (including the trivial intersections of a cone intersecting only itself) will form an atom of aggregation, which is call a clump. Clumps are created, represented by 606.

The number of clumps produced is now far smaller than the original number of blocks. Precedence arcs between clumps are induced by the precedence arcs between the individual blocks. An extraction ordering of the clumps that is feasible according to these precedence arcs will automatically respect minimum slope constraints. It is feasible to schedule these clumps to find a substantially NPV maximal, clump schedule 607 that satisfies all of the mining and processing constraints.

Now that there is a schedule of clumps 607, this can be turned into a schedule of individual blocks. One method is to consider all of those clumps that are begun in a calendar year one, and to excavate these block by block starting from the uppermost level, proceeding level by level to the lowermost level. Other methods are disclosed in Section 6 of this specification. Having produced this block ordering, the next step may be to optionally Polish 608 the block ordering to further improve the NPV.

In a more complex case, the step of polish 608, can be bypassed. If it is desirable, however, polishing can be performed to improve the value of the block sequence.

1.3 Balanced NPV optimal / mineable pushback design from block ordering

From this block ordering, we can produce pushbacks, via pushback design 609. Advantageously, the present invention enables the creation of pushbacks that allow for NPV optimal mining schedules. A pushback is a large section of a pit in which trucks and shovels will be concentrated to dig, sometimes for a period of time, such as for one or more years. The block ordering gives us a guide as to where one should begin and end mining. In essence, the block ordering is an optimal way to dig up the pit. However, often this block ordering is not feasible

because the ordering suggested is too spatially fragmented. In an aspect of invention, the block ordering is aggregated so that large, connected portions of the pits are obtained (pushbacks). Then a secondary clustering of the ore blocks can be undertaken 610. This time, the clustering is spatial (x, y, z) and has an additional 4th coordinate, which represents the block extraction time ordering. The emphasis of the 4th coordinate of time may be increased and decreased. Decreasing the emphasis produces clusters that are spatially compact, but ignore the optimal extraction sequence. Increasing the emphasis of the 4th coordinate produces clusters that are more spatially fragmented but follow the optimal extraction sequence more closely.

Once the clusters have been selected (and ordered in time), inverted cones are propagated upwards in time order. That is, the earliest cluster (in time) is propagated upwards to form an inverted cone. Next, the second earliest cluster is propagated upwards. Any blocks that are already assigned to the first cone are not included in the second cone and any subsequent cones. Likewise, any blocks assigned to the second cone are not included in any subsequent cones. These propagated cones or parts of cones form the pushbacks 611. This secondary clustering, propagation, and NPV valuation is relatively rapid, and the intention is that the user would select an emphasis for the 4th coordinate of time, perform the propagation and valuation, and view the pushbacks for mineability 612. A balance between mineability and NPV can be accessed 613, and if necessary the pushback design steps can be repeated, path 614. For example, if mineability is too fragmented, the emphasis of the 4th coordinate would be reduced. If the NPV from the valuation is too low, the emphasis of the 4th coordinate would be increased.

Once a pushback design has been selected, a minimum mining width routine 615 is run on the pushback design to ensure that a minimum mining width is maintained between the pushbacks and themselves, and the pushbacks and the boundary of the pit. An example in the open literature is "The effect of minimum mining width on NPV" by Christopher Wharton & Jeff Whittle, "Optimizing with Whittle" Conference, Perth, 1997.

1.4 Further valuation

A more sophisticated valuation method 616 is possible at this final stage that balances mining and processing constraints, and additionally could take into account stockpiling options, such as blending and supply chain determination and / or evaluation.

2 Initial identification of clusters

It has been found that the number of blocks in a block model is typically far too large to schedule individually, therefore in accordance with one related aspect of invention, the blocks are aggregated into larger collections. These larger collections are then preferably scheduled. Scheduling means assigning a clump to be excavated in a particular period or periods.

To proceed with the aggregation, a number of ore blocks are clustered. Ore blocks are identified as different from waste material. The waste material is to be removed to reach the ore blocks. The ore blocks may contain substantially only ore of a desirably quality or quantity and / or be combined with other material or even waste material. The ore blocks are typically located towards the bottom of the pit, but may be located any where in the pit. In accordance with a preferred aspect of the present invention, the ore blocks which are considered to be waste are given a negative value, and the ore blocks are not clustered with a negative value. It is considered that those blocks with a positive value, present themselves as possible targets for the staging of the open pit mine. This approach is built around targeting those blocks of value, namely those blocks with positive value. Waste blocks with a negative value are not considered targets and are therefore this aspect of invention does not cluster those targets. The ore blocks are clustered spatially (using their x, y, z coordinates) and in terms of their grade or value. Preferably, limits or predetermined criteria are used in deciding the clusters. For example, what is the spatial limit to be applied to a given cluster of blocks? Are blocks spaced 10 meters or 100 meters apart considered one cluster? These criteria may be varied depending on the particular mine, design and environment. For example, Figure 7 illustrates schematically an ore body 701. Within the ore body are a number of blocks 702, 703, 704 and 705. (The ore body has many blocks, but the description will only refer to a limited number for simplicity) Each block 702, 703, 704 and 705 has its own individual x, y, z

coordinates. If an aggregation is to be formed, the coordinates of blocks 702, 703, 704 and 705 can be analysed according to a predetermined criteria. If the criteria is only distance, for example, then blocks 702, 703 and 704 are situated closer than block 705. The aggregation may be thus formed by blocks 702, 703 and 704. However, if, in accordance with this aspect of invention, another criteria is also used, such as grade or value, blocks 702, 703 and 705 may be considered an aggregation as defined by line 706, even though block 704 is situated closer to blocks 702 and 703. A balance is struck between having spatially compact clusters, and clusters with similar grade or value within them. These clusters will form the kernels of the atoms of aggregation. It is important that there is control over spatial compactness versus the grade/value similarity. If the clusters are too spatially separated, the inverted cone that we will ultimately propagate up from the cluster (as will be described below) will be too wide and contain superfluous stripping. If the clusters internally contain too much grade or value variation, there will be dilution of value. It is preferable for the clusters to substantially sharply identify regions of high grade and low-grade separately, while maintaining a spatial compactness of the clusters. Such clusters have been found to produce high-quality aggregations.

Furthermore, where a relatively large body of ore is encountered, the ore body may be divided into a relatively large number of blocks. Each block may have substantially the same or a different ore grade or value. A relatively large number of blocks will have spatial difference, which may be used to define aggregates and clumps in accordance with the disclosure above. The ore body, in this manner may be broken up into separate regions, from which individual cones can be defined and propagated.

3 Propagation of clusters and formation of clumps

In accordance with the present invention, from each cluster, an inverted cone (imaginary) is formed. A cone is referred to as a manner of explaining visually to the reader what occurs. Although the collection of blocks forming the cone does look like a discretised cone to the human eye. In a practical embodiment, this step would be simulated mathematically by computer. Each cone is preferably a minimal cone, that is, not over sized. This cone is represented schematically or mathematically, but for the purposes of explanation

it is helpful to think of an inverted cone propagating upward of the aggregation. The inverted cone can be propagated upwards of the atom of aggregation using the precedence arcs. Most mine optimisation software packages use the idea of precedence arcs. The cone is preferably three dimensional. The inverted cone represents the minimal amount of material that must be excavated before the entire cluster can be extracted. In accordance with a preferred form of this aspect of invention, every cluster has a corresponding inverted cone.

Typically, these cones will intersect another cone propagating upwardly from an adjacent aggregation. Each intersection (including the trivial intersections of a cone intersecting only itself) will form an atom of aggregation, which is call a 'clump', in accordance with this aspect. Precedence arcs between clumps are induced by the precedence arcs between the individual blocks. These precedence arcs are important for identifying which extraction ordering of clumps are physically feasible and which are not. Extraction orderings must be consistent with the precedence arcs. This means that if block/clump A points to block/clump B, then block/clump B must be excavated earlier than block/clump A.

With reference to Figure 8, illustrating a pit 801, in which there are ore bodies 802, 803, and 804. Having identified the important "ore targets" in the stage of initial identification of clusters, as described above, the procedure of propagation and formation of clumps goes on to produce mini pits (clumps) that are the most efficient ways access these "ore targets". The clumps are the regions formed by an intersection of the cones, as well as the remainder of cones once the intersected areas are removed. In accordance with the embodiment aspect, intersected areas must be removed before any others. Eg. 814 must be dug up before either 805 or 806, in Figure 8. In accordance with the description above, cones 805, 806 and 807 are propagated (for the purposes of illustration) from ore bodies to be extracted. The cones are formed by precedence arcs 808, 809, 810, 811, 812 and 813. In Figure 8, for example, clumps are designated regions 814 and 815. Other clumps are also designated by what is left of the inverted cones 805, 806 and 807 when 814 and 815 have been removed. The clump area is the area within the cone. The overlaps, which are the intersections of the cones, are used to allow the excavation of the inverted cones in any particular order. The collection of clumps has three important properties. Firstly,

the clumps allow access to the all targets as quickly as possible (minimality), and secondly the clumps allow many possible orders of access to the identified ore targets (flexibility). Thirdly, because cones are used, an extraction ordering of the clumps that is feasible according to the precedence arcs will automatically respect and accommodate minimum slope constraints. Thus, the slope constraints are automatically built into this aspect of invention.

4 Splitting of waste and ore in clumps

Once the initial clumps have been formed, a search is performed from the lowest level of the clump upwards. The highest level at which ore is contained in the clump is identified; everything above this level is considered to be waste. The option is given to split the clump into two pieces; the upper piece contains waste, and the lower piece contains a mixture of waste and ore. Figure 9 illustrates a pit 901, in which there is an ore body 902. From the ore body, precedence arcs 903 and 904 define a cone propagating upward. In accordance with this aspect of invention, line 905 is identified as the highest level of the clump 902. Then 906 can designate ore, and 907 can designate waste. This splitting of waste from ore designations is considered to allow for a more accurate valuation of the clump. Many techniques assume that the value within a clump is uniformly distributed, however, in practice this is often not the case. By splitting the clump into two pieces, one with pure waste and the other with mostly ore, the assumption of homogeneity is more likely to be accurate. More sophisticated splitting based on finer divisions of value or grade are also possible in accordance with predetermined criteria, which can be set from time to time or in accordance with a particular pit design or location.

5 Aggregation of blocks into clumps: high-level ideas

In accordance with this aspect, the feature of 'clumping blocks together' may be viewed for the purpose of arithmetic simplicity where the number of blocks are too large. The number of clumps produced is far smaller than the original number of blocks. This allows a mixed integer optimisation engine to be used, otherwise the use of mixed integer engines would be considered not feasible. For example, Cplex by ILOG may be used. This aspect has beneficial application to the invention disclosed in pending provisional patent application no. PS1099, titled "Mining Process and Design" filed 14 March 2002 by the present

applicant, and which is herein incorporated by reference. This aspect can be used to reduce problem and calculation size for other methods (such as disclosed in the co-pending application above).

The number of clumps produced is far smaller than the original number of blocks. This allows a mixed integer optimisation engine to be used. The advantage of such an engine is that a truly optimal (in terms of maximising NPV) schedule of clumps may be found in a (considered) feasible time. Moreover this optimal schedule satisfies mining and processing constraints. Allowing for mining and processing constraints, the ability to find truly optimal solutions represents a significant advance over currently available commercial software. The quality of the solution will depend on the quality of the clumps that are input to the optimisation engine. The selection procedures to identify high quality clumps have been outlined in the sections above.

Some commercial software, as noted in the background section of this specification, do use mixed integer programming engines, however, the method of aggregating blocks is different either in method, or in application, and we believe of lower-quality. For example, it is considered that 'ECSI Maximiser' uses a form of integer optimisation in their pushback design, and restricts the time window for each block, but the optimisation is local in time, and it's problem formulation is considered too large to optimise globally over the life of a mine. In contrast, in accordance with the present invention, a global optimisation over the entire life of mine is performed by allowing clumps to be taken at any time from start of mine life to end of mine life. 'MineMax' may be used to find rudimentary optimal block sequencing with a mixed integer programming engine, however it is considered that it's method of aggregation does not respect slopes as is required in many situations. 'MineMax' also optimises locally in time, and not globally. In use, there is a large huge number of variables, and the user must therefore resort to subdividing the pit to perform separate optimisations, and thus the optimisation is not global over the entire pit. The present invention is global in both space and time.

6 Determination of a block ordering from a clump ordering

Now that there is a schedule of clumps, it is desirable to turn this into a schedule of individual blocks. One method is to consider all of those clumps that

are begun in year one, and to excavate these block by block starting from the uppermost level, proceeding level by level to the lowermost level. One then moves on to year two, and considers all of those clumps that are begun in year two, excavating all of the blocks contained in those clumps level by level from the top level through to the bottom level. And so on, until the end of the mine life.

Typically, some clumps may be extracted over a period of several years. This method just described is not as accurate as may be required for some situations, because the block ordering assumes that the entire clump is removed without stopping, once it is begun. Another method is to consider the fraction of the clump that is taken in each year. This method begins with year one, and extracts the blocks in such a way that the correct fractions of each clump for year one are taken in approximately year one. The integer programming engine assigns a fraction of each clump to be excavated in each period/year. This fraction may also be zero. This assignment of clumps to years or periods must be turned into a sequence of blocks. This may be done as follows. If half of the clump A is taken in year one, and one third of clump B is taken in year one, and all other fractions of clumps in year one are zero, the blocks representing the upper half of clump A and the blocks representing the upper one-third of clump B are joined together. This union of blocks is then ordered from the uppermost bench to the lowermost bench and forms the beginning of the blocks sequence (because we are dealing with year one). One then moves on to year two and repeats the procedure, concatenating the blocks with those already in the sequence.

Having produced this block ordering, block ordering may be in a position to be optionally Polished to further improve the NPV. The step of Polishing is similar to the method disclosed in co-pending application PS1099 (described above, and incorporated herein by reference) but the starting condition is different. Rather than best value to lowest value, as is disclosed in the co-pending application, in the present aspect, the start is with the block sequence obtained from the clump schedule.

7 Second Identification of clusters for pushback design

7.1 Fuzzy clustering; alternative 1 (space/time clustering of block sequence)

From this block ordering, we must produce pushbacks. This is the ultimate goal of KlumpKing - to produce pushbacks that allow for NPV optimal mining schedules. A pushback is a large section of a pit in which trucks and shovels will be concentrated for one or more years to dig. The block ordering gives us a guide as to where one should begin and end mining. In principle, the block ordering is the optimal way to dig up the pit. However, it is not feasible, because the ordering is too spatially fragmented. It is desirable to aggregate the block ordering so that large, connected portions of the pits are obtained (pushbacks). A secondary clustering of the ore blocks is undertaken. This time, clustering is spatially (x, y, z) and as a 4th coordinate, which is used for the block extraction time or ordering. The emphasis of the 4th coordinate of time may be increased or decreased. Decreasing the emphasis produces clusters that are spatially compact, but tend to ignore the optimal extraction sequence. Increasing the emphasis produces clusters that are more spatially fragmented but follow the optimal extraction sequence more closely.

Once the clusters have been selected, they may be ordered in time. The clusters are selected based on a known algorithm of fuzzy clustering, such as JC Bezdek, RH Hathaway, MJ Sabin, WT Tucker. "Convergence Theory for Fuzzy c-means: Counterexamples and Repairs". IEEE Trans. Systems, Man, and Cybernetics 17 (1987) pp 873-877. Fuzzy clustering is a clustering routine that tries to minimise distances of data points from a cluster centre. In this inventive aspect, the cluster uses a four-dimensional space; (x, y, z, v), where x, y and z give spatial coordinates or references, and 'v' is a variable for any one or a combination of time, value, grade, ore type, time or a period of time, or any other desirable factor or attribute. Other factors to control are cluster size (in terms of ore mass, rock mass, rock volume, $value, average grade, homogeneity of grade/value), and cluster shape (in terms of irregularity of boundary, sphericalness, and connectivity). In one specific embodiment, 'v' represents ore type. In another embodiment, clusters may be ordered in time by accounting for 'v' as representing clusters according to their time centres.

There is also the alternative embodiment of controlling the sizes of the clusters and therefore the sizes of the pushbacks. "Size" may mean rock tonnage, ore tonnage, total value, among other things. In this aspect, there is provided a fuzzy clustering algorithm or method, which in operation serves to, where if a pushback is to begin, its corresponding cluster may be reduced in size by reassigning blocks according to their probability of belonging to other clusters.

There is also another embodiment, where there is an algorithm or method that is a form of 'crisp', as opposed to fuzzy, clustering, specially tailored for the particular type of size control and time ordering that are found in mining applications. This 'crisp' clustering is based on a method of slowly growing clusters while continually shuffling the blocks between clusters to improve cluster quality.

7.2 Fuzzy clustering; alternative 2 (Propagation of clusters)

Having disclosed clustering, above, another related aspect of invention is to then propagate these clusters in a time ordered way without using intersections, to produce the pushbacks.

Referring to Figure 10, a mine site 1001 is schematically represented, in which there is an ore body of 3 sections, 1002, 1003, and 1004.

Inverted cones are then propagated upwards in a time order, as represented in Figure 10, by lines 1005 and 1006 for cone 1. That is, the earliest cluster (in time) is propagated upwards to form an inverted cone. Next, the second earliest cluster is propagated upwards, as represented in Figure 10 by lines 1007 and 1008 (dotted) for cone 2, and lines 1009 and 1010 (dotted) for cone 3. Any blocks that are already assigned to the first cone are not included in the second cone. This is represented in Figure 10 by the area between lines 1008 and 1005. This area remains a part of cone 1 according to this inventive aspect. Again, in Figure 10, the area between lines 1010 and 1007 remains a part of cone 2, and not any subsequent cone. This method is applied to any subsequent cones. Likewise, any blocks assigned to the second cone are not included in any subsequent cones. These propagated cones or parts of cones form the pushbacks.

7.3 Fuzzy Clustering; alternative 3 (Feedback loop of pushback design)

In this related aspect, there is a process loop of clustering, propagating to find pushbacks, valuing relatively quickly, and then feeding this information back into the choice of clustering parameters.

This secondary clustering, propagation, and NPV valuation is relatively rapid, and the intention is that there would be an iterative evaluation of the result, either by computer or user , and accordingly the emphasis for the 4th coordinate can be selected, the propagation and valuation can be considered and performed, and the pushbacks for mineability can also be considered and reviewed. If the result is considered too fragmented, the emphasis of the 4th coordinate may be reduced. If the NPV from the valuation is too low, the emphasis of the 4th coordinate may be increased.

Referring to Figure 11a, there is illustrated in plan view a two dimensional slice of a mine site. In the example there are 15 blocks, but the number of blocks may be any number. In this example, blocks have been numbered to correspond with extraction time, where 1 is earliest extraction, and 15 is latest extraction time. In the example illustrated, the numbers indicate relatively optimal extraction ordering.

In accordance with the aspect disclosed above, Figure 11b illustrates an example of the result of clustering where there is a relatively high fudge factor and relatively high emphasis on time. Cluster number 1 is seen to be fragmented, has a relatively high NPV but is not considered mineable.

In accordance with the aspect disclosed above, Figure 11c illustrates an example of the result of clustering where there is a lower emphasis on time, as compared to Figure 11b. The result illustrated is that both clusters number one and two are connected, and 'rounded', and although they have a slightly lower NPV, the clusters are considered mineable.

As the present invention may be embodied in several forms without departing from the spirit of the essential characteristics of the invention, it should be understood that the above described embodiments are not to limit the present invention unless otherwise specified, but rather should be construed broadly within the spirit and scope of the invention as defined in the appended claims. Various modifications and equivalent arrangements are intended to be included

within the spirit and scope of the invention and appended claims. Therefore, the specific embodiments are to be understood to be illustrative of the many ways in which the principles of the present invention may be practiced. In the following claims, means-plus-function clauses are intended to cover structures as performing the defined function and not only structural equivalents, but also equivalent structures. For example, although a nail and a screw may not be structural equivalents in that a nail employs a cylindrical surface to secure wooden parts together, whereas a screw employs a helical surface to secure wooden parts together, in the environment of fastening wooden parts, a nail and a screw are equivalent structures.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method of determining a schedule for extraction of clump(s), the method including:
determining a period of time corresponding to at least a portion of the clump(s), and
assigning the period of time to the portion of clump(s).

2. A method as claimed in claim 1, wherein the steps are repeated for other portion(s) of clump(s).

3. A method as claimed in claim 1, wherein the portion is zero.

4. A method as claimed in claim 1, 2 or 3, wherein the portion of clump(s) is assigned a period of time on the basis of predetermined attributes.

5. A method of determining an extraction order of block(s) from corresponding clump schedule, the method including:
performing the method as claimed in any one of claims 1 to 4,
determining which portion(s) of clump(s) have been assigned the same period of time, and
joining together blocks located in the portion(s) having the same period of time.

6. A method as claimed in claim 5, wherein the order is determined by extracting blocks from an uppermost sequence of blocks through to a lower sequence of blocks.

7. A method as claimed in claim 5 or 6, further including the step of refining the block order to improve NPV.

8. A method as claimed in claim 7, wherein the refining of NPV is initiated from the block sequence obtained from a clump schedule.

9. A mine designed in accordance with the method as claimed in any one of claims 1 to 8.

10. Material extracted from a mine in accordance with the design as claimed in claim 9.

11. Material extracted from a mine in accordance with the method as claimed in any one of claims 1 to 8.

12. A computer program product including:

computer usable medium having computer readable program code and computer readable system code embodied on said medium for determining slope constraints related to a design configuration for extracting material from a particular location within a data processing system, said computer program product including:

computer readable code within said computer usable medium for performing the method as claimed in any one of claims 1 to 8.

13. A method and / or device as herein disclosed.

14. A method as claimed in any one of claims 1 to 8, substantially as herein described with reference to the accompanying drawings.

15. Apparatus adapted to determining a schedule for extraction of clump(s), the apparatus including:

first means for determining a period of time corresponding to at least a portion of the clump(s), and

second means for assigning the period of time to the portion of clump(s).

16. Apparatus adapted to determining an extraction order of block(s) from corresponding clump schedule, the apparatus including:

first means for performing the method as claimed in any one of claims 1 to 4,

second means for determining which portion(s) of clump(s) have been assigned the same period of time, and

third means for joining together blocks located in the portion(s) having the same period of time.

17. Apparatus including a processor means adapted to operate in accordance with a predetermined instruction set,

said apparatus, in conjunction with said instruction set, being adapted to perform the method as claimed in any one of claims 1 to 8, 13 or 14.

DATED THIS 9th day of October 2002

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Kangaroo Ground Vic 3097
Australia

Figure 1
(prior art)

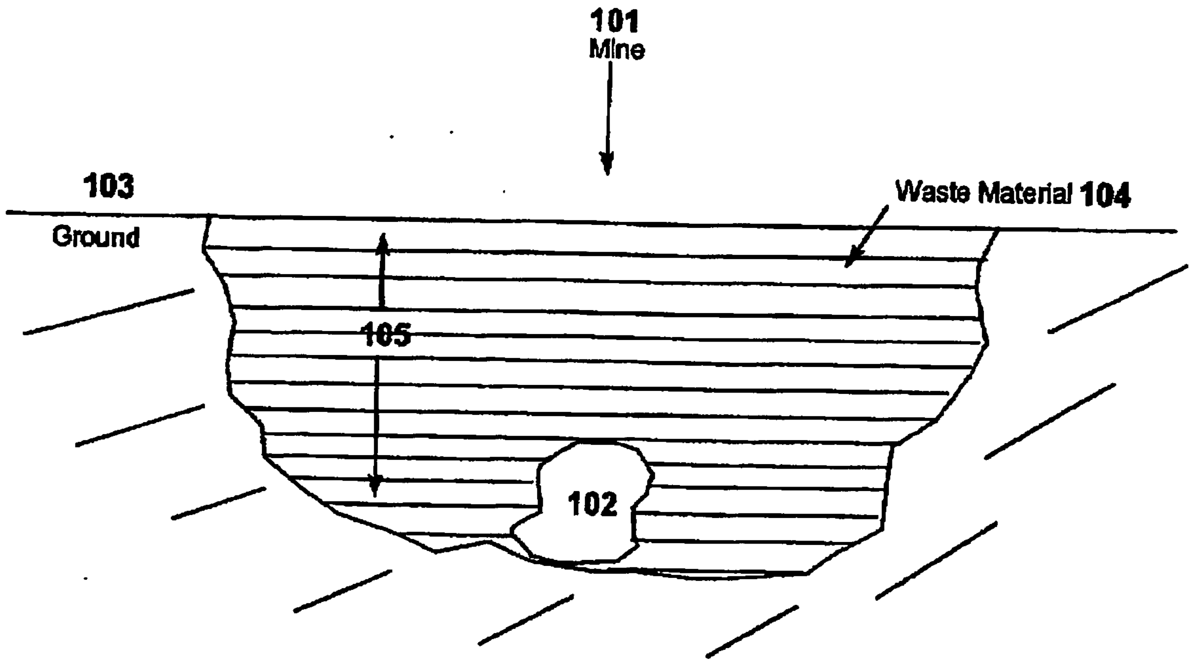


Figure 2
prior art

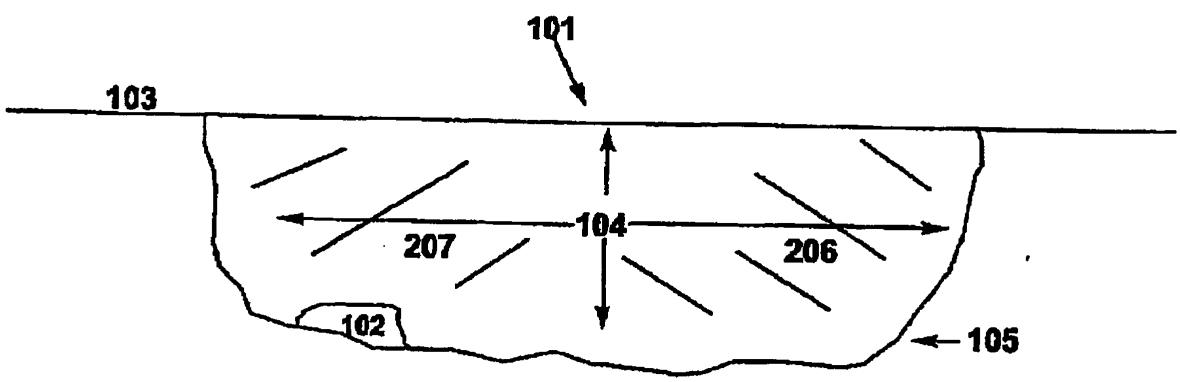
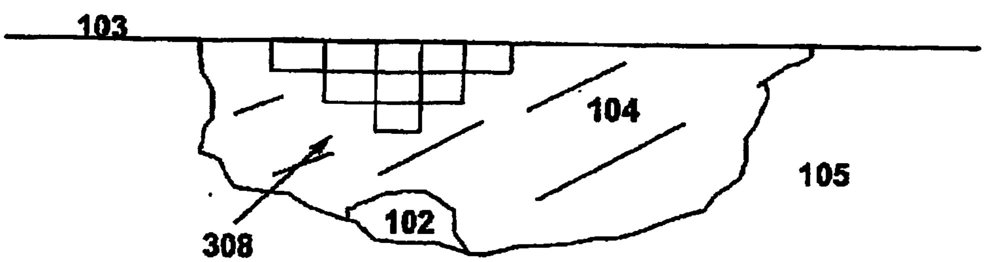


Figure 3
prior art



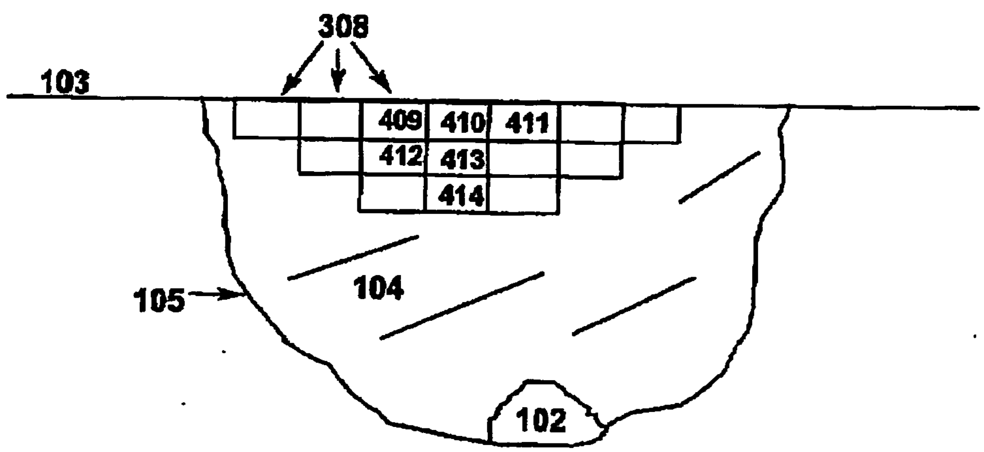
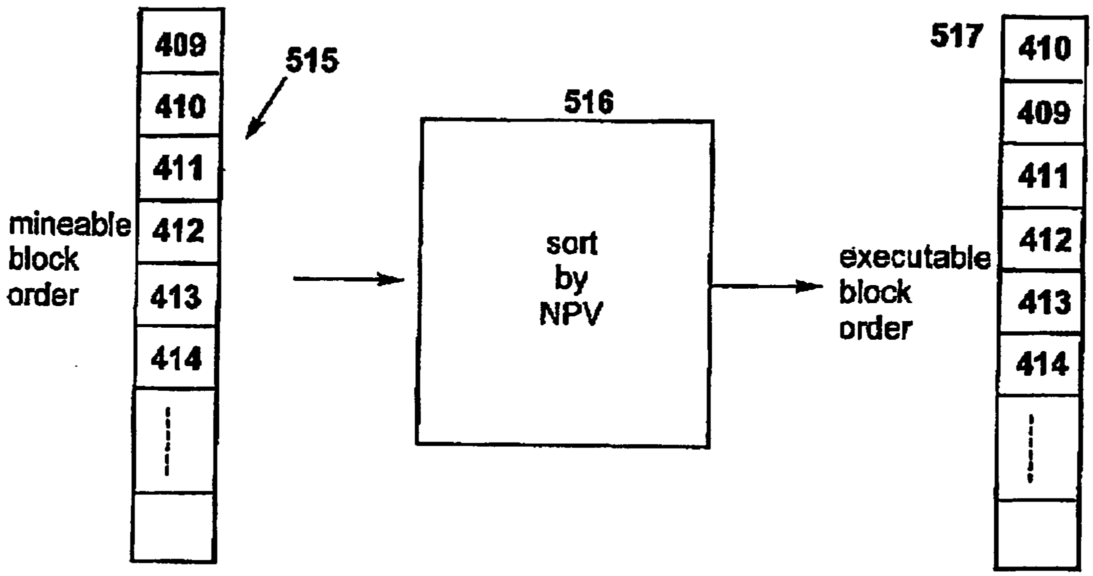


Figure 4
prior art

Figure 5
prior art



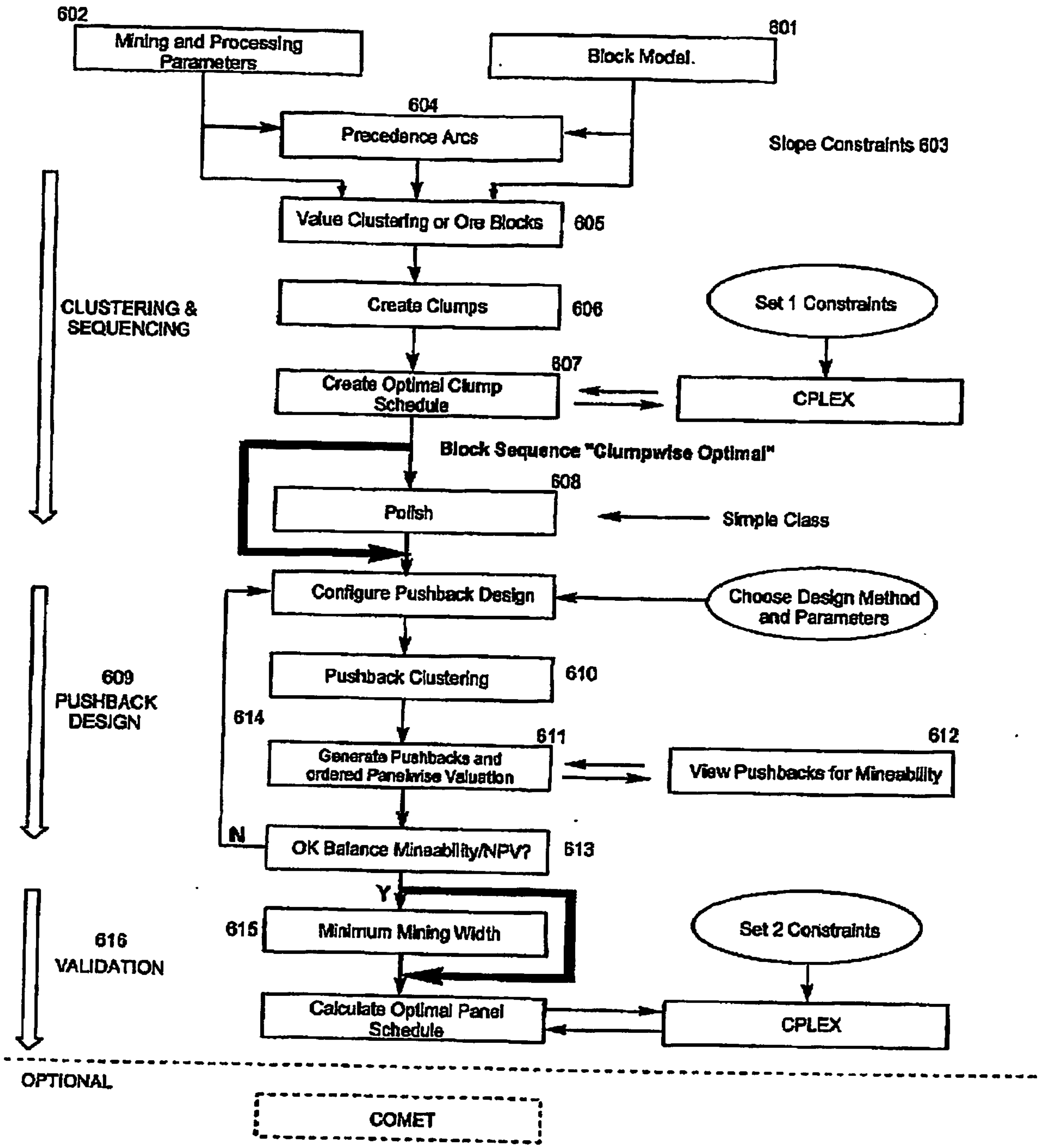


Figure 6 KlumpKing Top-Level Flow Chart

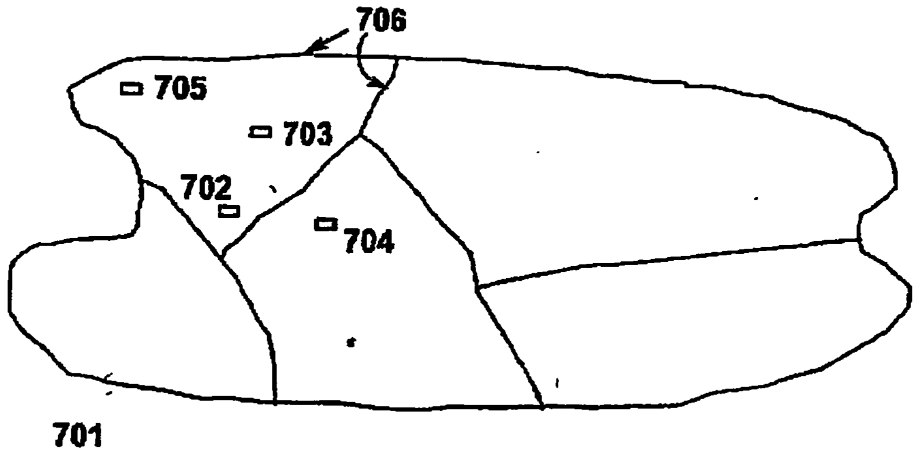


Figure 7

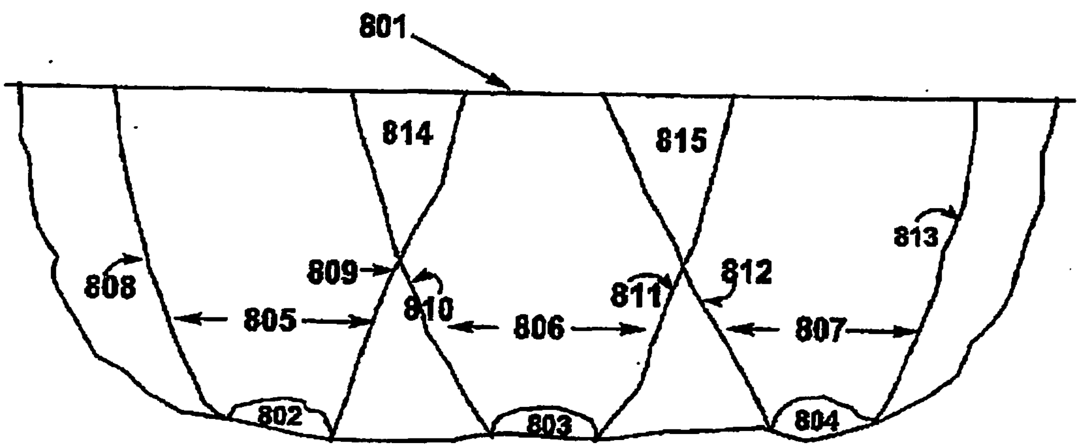


Figure 8

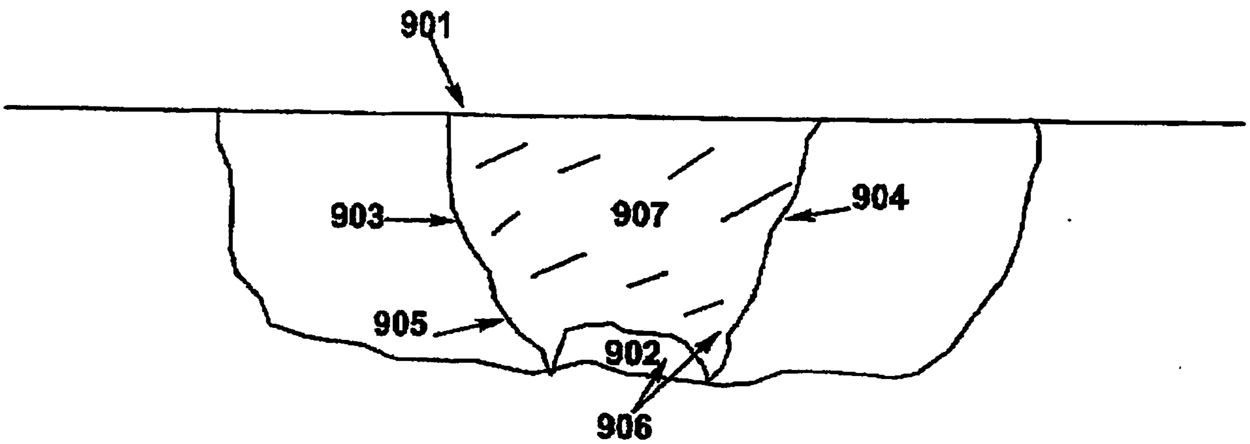


Figure 9

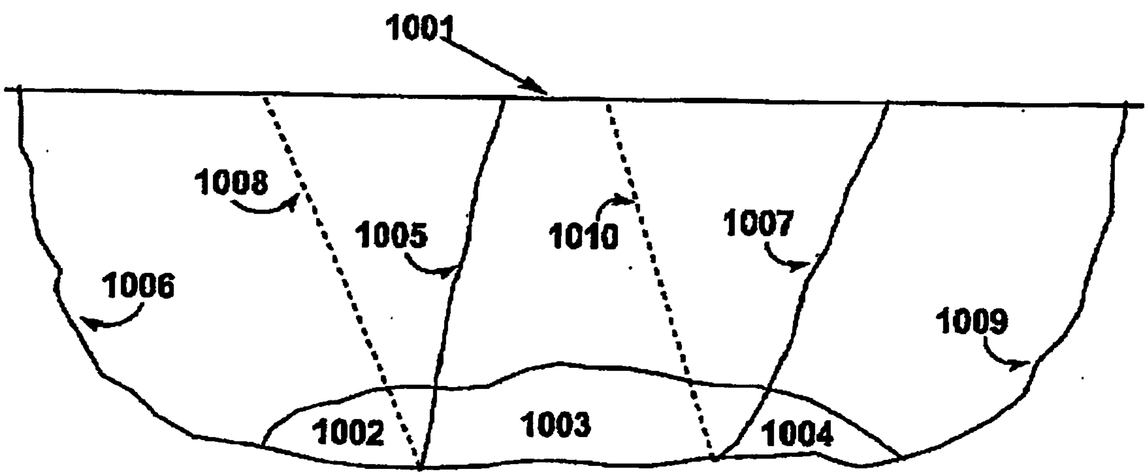


Figure 10

Plan view : 2D block slice

1	8	13	2	3
11	9	14	4	6
10	12	15	7	5

Figure 11a

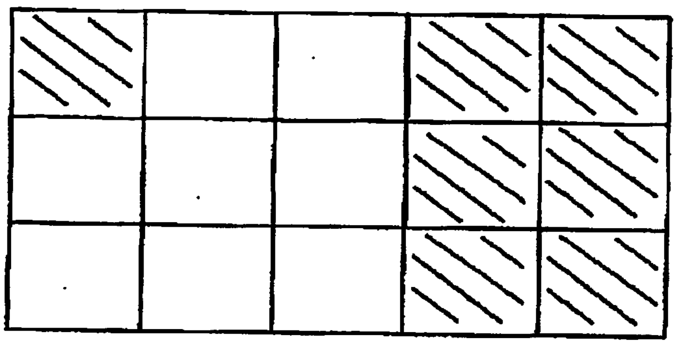


Figure 11b

= cluster #1

= cluster #2

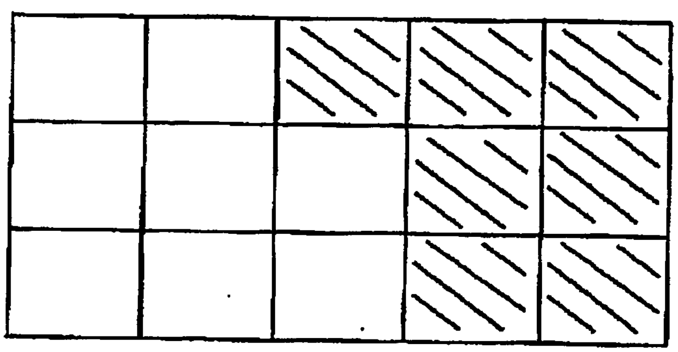


Figure 11c

= cluster #1

= cluster #2